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# Through Life Management of Naval Gas Turbines for Extended Service Lives and Reduced Lifetime Costs

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## INTRODUCTION

Marine gas turbines have been used for many decades in a diverse range of commercial and naval marine vessels, almost exclusively for main propulsion duties in a number of different configurations. As well as providing an outline of the scope of operation, this paper aims to discuss the key Life Extension Programmes and Cost Reduction Strategies developed by the UK Ministry of Defence in support of the two international collaborative Memoranda of Understanding (MoU) for the marine Olympus, Tyne and Spey gas turbines. Where available, discussion is supported with evidence from emerging equipment maintenance policies, equipment modifications and data collected from components and engines returned from the fleet for repair or overhaul. In addition, and in terms of the economy of scale advantages that the arrangements offer, an assessment of accumulated savings and projected financial return is provided with an insight into the operational benefits and improved capability that the programmes realise.

The UK Warship Support Agency (WSA) provides overarching in-service gas turbine support and cooperation through two Memoranda of Understanding (MoU) involving 4 European nations, 21 years of collaboration and 3 million shared running hours of operation. The membership of the Olympus TM3B and Tyne RM1C MoU, in place since 1980, comprises of the UK, The Netherlands, France and Belgium. The MoU for the Spey SM1A, signed in 1989, is between the UK and The Netherlands. In addition, the Royal Navy (RN) also operates the Rolls Royce Spey SM1C and, from 2002, will be accompanied by The Royal Netherlands Navy (RNLN) under an extended Spey MoU to encompass the engines installed in their new class of Logistic Command Frigates.

Engine Variant	Fleet Seats				Spare Engines	Total
	RN	RNLN	BN	FN		
Olympus	43	12	3	14	17	89
Tyne	35	12	-	-	23	70
Spey SM1A	25	16	-	-	9	50
Spey SM1C	16	6	-	-	6	28

## BACKGROUND

### Engine configurations :

Olympus engines are rated at 18 MW and Tyne at 4 MW. Generally both engines are used in a Combined Gas or Gas configuration (COGOG), however, in French and Belgian Navies, the Olympus operates in combination with direct acting diesel engines under a Combined Diesel or Gas (CODOG) arrangement. Depending on the class of vessel, the Spey is used at ratings of either 12.75 MW or 18 MW in combination either with the Tyne in a COGOG arrangement or with diesel engines either in a Combined Diesel Electric and Gas (CODLAG) mode of operation (Figure 1) or in a Combined Diesel and Gas (CODAG) configuration.

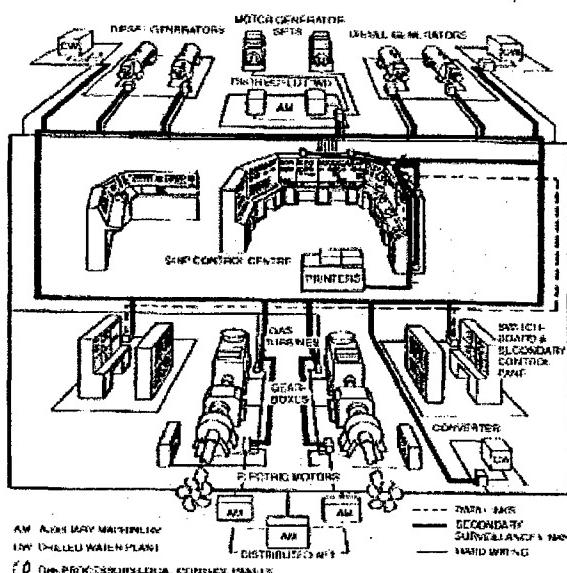


Figure 1 - Type 23 Frigate CODLAG Propulsion Machinery Layout.

Despite many permutations of operation this presents no real problems in terms of support, however, careful attention is required in considering and then managing the effects of

different mission profiles on component lives, in particular the effects of Low Cycle Fatigue (LCF).

All MoU partner navies operate using the principle of cruise and boost. In the case of a Tyne and Spey configuration as used in the last batch of Type 22 Frigates, the smaller Tyne unit is used as the cruise engine while the Spey is used for sprinting when operational commitment necessitates. The reason this configuration was chosen is due to the initial projected operational speed profile combined with the necessary utilisation of ship propulsive power and the relatively high fuel consumption of the Spey at low powers (Figure 2).

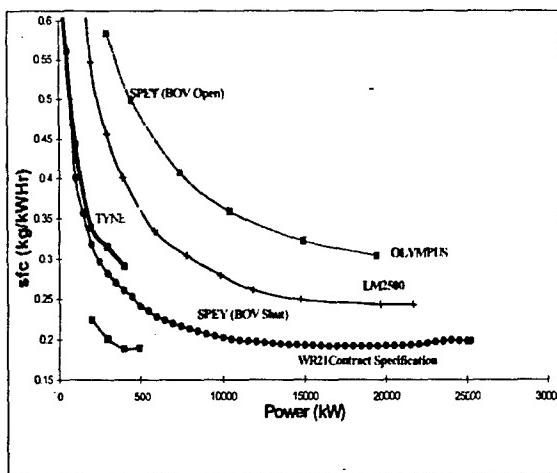


Figure 2 - Comparison of prime mover Specific Fuel Consumption.

In Frigates and Destroyers of the RN and RNLN, 25 % of the total available propulsion power is sufficient for 80 % of all operations (Figure 3).

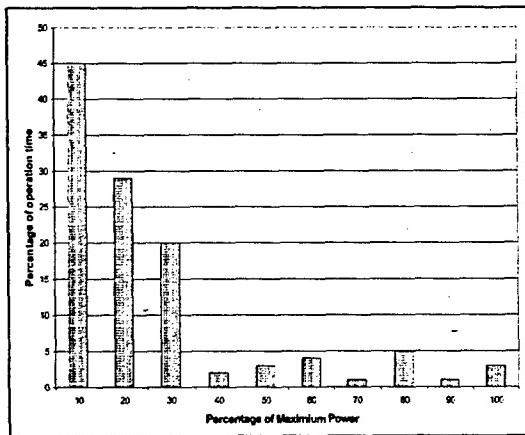


Figure 3 - FF/DD engine power band distribution.

The larger boost engines have relatively high fuel consumption at lower powers, and prolonged running at this condition is clearly undesirable.

This configuration allows for reasonable fuel economy to be obtained: at moderate to low ship speeds, by using the smaller cruise gas turbines; for higher ship speeds, the boost gas turbine is used. The arrangement enables a higher degree of ship operation at the relatively flat portion of the selected engine's SFC (Specific Fuel Consumption) curve, which for the simple cycle gas turbines being operated generally occurs above 80 % of rated power output.

This installation facilitates operational flexibility, but at the penalty of a relatively large number of installed propulsion prime movers, some of which will spend a large percentage of ship operational time not in use.

This is particularly the case in the post cold war era, where naval ship operating profiles have changed, and more specifically the demand for greater fuel economy has led to a situation where the boost gas turbines accumulate sometimes less than 300 hours per year, with the majority of running on cruise engines.

#### Objective of the MoU agreements :

A prime objective of each agreement is to minimise in-service support costs for all partners through the principle of economy of scale of common items using a pool of Gas Turbine Change Units and engine spares and the provision of mutual engineering, logistic and financial support. This reduces any single nation's commitment significantly below that required if it were solely a national programme. It also provides the flexibility to react to the unpredicted enabling tauter contracts and reduced turn around times for repair and overhaul. A largely identical hardware standard and similar utilisation means it is also possible to apply common logistic, maintenance and engineering procedures.

Overarching the above is the requirement to maintain design standards and ensure safe operation within the RN and other MoU fleets. Whilst the Design Authority, Rolls Royce, is supportive, each participating navy is responsible for its own 'day to day' fleet support activities whether this is in the form of gas turbine operational problem solving, condition monitoring, performance trending or predictive maintenance. The role in the UK rests with MPS214, a sub division within the Marine Propulsion System Integrated Project Team (MPS IPT) currently based in Bath but relocating to Bristol in 2002.

In addition to aforementioned activities, other key interests lay in :

- managing technical and financial Post Design Support activities on Rolls Royce,
- maintaining and operating the in-house Logistic Support Model (LSM) for the prediction of R&O arisings and the generation of costed management data (Figure 4),

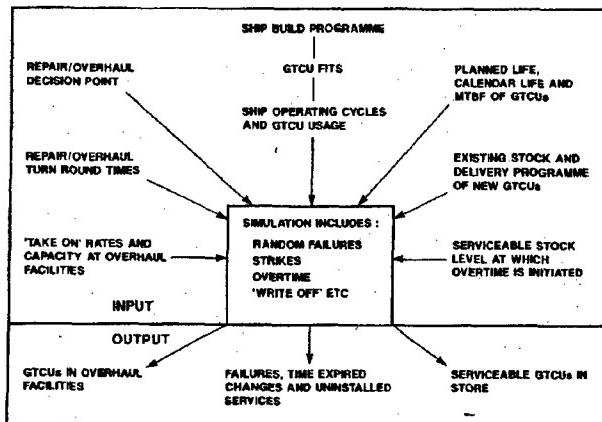


Figure 4 - The Gas Turbine Logistic Support Model .

- monitoring reliability, overhaul costs and technical information, reporting output to the partners through the mechanism of a Management Information System,
- liaising with the Design Authority and MoU partners in developing component and engine life assessment and extension strategies, taking into account any 'MoU rundown' implications,
- generating and implementing through life cost reduction initiatives and developing novel support mechanisms and gainshare initiatives with contractors,
- keeping abreast of technology with a view to its acceptability into service to solve discrete engineering issues,
- promoting information exchange internally (with the Royal Air Force Propulsion Support Group) and externally to foreign nations, future UK projects and industry.

The decision on UK management of the MoU's was made at the outset and was based on the fact that the UK MoD already had, at that time, considerable experience of in-service support and the necessary organisation in place. This was coupled with the fact that the RN was, and remains, the major stakeholder in having the largest number of engines in operation.

#### **Problems faced in marine gas turbine operation :**

Naval marine gas turbines have served well in the last four decades as main propulsion prime movers, enabling many of the original benefits to be realised. Derived almost exclusively from aero-engine parentage and having a good deal of operational experience, their use, however, in a harsh marine domain is somewhat demanding, with dissimilar operating profiles and environments ;

- highly variable mission profile, the majority of which historically has been at part-load with sudden load changes,
- salt and sand laden intake air, necessitating careful selection of intake filtration, corrosion resistant coatings and materials,
- the consequence of reducing vulnerability and increasing sea going stability now means that operating location presents longer intake and exhaust ducting than equivalent aero or industrial applications,
- variation in fuel quality and calorific value, due to embarkation from various global sources and standards,
- variable ambient conditions experienced during unrestricted global operation (Arctic to Middle East).

All of these issues place varying degrees of risk on reliability, durability and performance and as such must be overcome in order to reduce premature failures and increase the intervals between overhaul (IBO).

#### **STRATEGIES IN REDUCING THROUGH LIFE COSTS**

##### **Current strategy :**

As a strategy in the reduction of through life investment, the principal objective is to reduce overall Life Cycle Costs for all engines and to this end real improvements in component and engine reliability and availability are being sought by reducing the number of premature removals; where they are safety related, where they threaten operational effectiveness and where significant savings can be achieved over remaining life through cost effective investment. Other key factors are the application of a successful through life management programme to increase IBO's combined with the successful application of risk management in arriving at availability / capability tradeoffs.

Early engine life extension initiatives were based solely on endoscope inspections of gas path components. Understandably, these were not well received by the Design Authority who felt uncomfortable in basing advice to their customer on a limited understanding of component condition rather than being in a position of monitoring trends in performance and gradual deterioration. The additional argument was that specialist advice and experience from using other engines was also not being taken into account when arriving at conclusions.

Following discussions in 1996 between Rolls Royce and MPS214, a dedicated programme aimed at extending the IBOs for the Olympus and Tyne engines were defined and agreed between the two parties. A similar programme for the modular Spey SM1A engine was derived and in place by 1997 but this did not include the SM1C currently in RN operation as the declared overhaul lives for the modules are generally far superior to those in SM1A reflecting a number of material and performance improvements the SM1C embodies over the SM1A.

On reflection, it could be argued that as a Design and Overhaul Authority, Rolls Royce (or in fact any OEM) have no operator experience of their own, relying entirely on their customers for feedback on performance, defects and running issues in order for new generation products to evolve. Whilst it could be surmised that there is also a financial disincentive for any authority as an overhaul facility to extend engine lives, the programmes finally negotiated with the company are now both relevant and appropriate in scale to both parties. Working with a limited resource and a highly motivated team within MPS214, these strategies continue to provide very significant returns in increasing reliability and reducing the overall cost of operation of the engines.

However, not all returns are generated from the drive to increase overhaul lives, some are reflected in the group's wish to retain its intelligent customer status. MPS214 employs a mix of service personnel and qualified civilian staff, some with many years of experience whether in gas turbine operation or equipment / project management. This allows the group to frequently take the first step in any initiative to extend condition based performance, however, this necessitates an inherent

degree of risk which must firstly be qualified and analysed prior to making any decision which may impact on engine and operator safety, platform availability or operational commitment.

#### ACHIEVING VALUE FOR MONEY IN PRACTICE :

The following details provide a summary of the key initiatives in place to achieve the overall aims of; increased engine reliability, increased availability and time on platform, reduced operator maintenance, reduced turnover of spares and reduced costs attributable to R&O. An assessment of some of the accumulated savings and projected financial return is provided alongside an insight into the operational benefits and improved capability that each of the initiatives has, and will, realise.

#### Engine Life Assessment and Extension Programmes :

For each gas turbine variant, the core of each managed programme consists of a number of well planned and documented in-service inspections on a small number of nominated engines at specified intervals. Upon removal, these engines also undergo an additional conditional assessment during overhaul, however, Critical Component Lives remain independent of the Interval Between Overhaul and this aspect of the lifeing policy is managed alongside the three extension programmes.

In terms of the immediate objectives, initial stages of each programme have proved to be both realistic and achievable demonstrating the benefits of undertaking a strategy developed through close relationship between the Design Authority and the customer, Table 2 refers.

In addition to the operational benefits and flexibility to the Command from the increased installed lives, the extended IBOs are already resulting in very significant reductions in MOU engine overhaul bills. A direct collective saving between all three engines of approximately £ 3.0 M per year is currently being made. One could debate the actual value, however, in perspective, this represents a 28 % reduction in the marine gas turbine overhaul budget and the analysis does not include the increase in operational capability that arises.

#### **The Tyne Life Extension Programme :**

The Tyne engine in its 'cruise' role accumulates by far the most running hours of the three variants. By concentrating maintenance and improvement efforts on this engine, the highest returns on investments are being achieved.

The strategy of the Life Extension Programme is to conduct a series of detailed in-service inspections and performance condition assessments commencing on each engine at around 75 % of the IBO. This is then followed by an inspection at around 4800 hours of operation and if engine health is satisfactory then release life is extended incrementally, usually in stages of 500 or 1000 hours, to 6500 hours. Inspections are repeated until the engine is sentenced as unfit for further running.

Where possible, further engine operation is granted by exception, usually to undertake discrete operational requirements. That said, successes so far include an RNLN engine that had accrued 8000 hours prior to life expiry, an increase in IBO of 60 % over the original declared overhaul life.

The limitations of a gas path component inspection are, however, fully recognised. High risk areas such as bearings, oil seals and labyrinth elements are not immediately visible but may have potentially threatening consequences in terms of safety of engine operation and performance if they are allowed to degrade without being monitored. For this reason, decisions regarding life extension are strengthened with evidence from component analysis undertaken on high life engines during overhaul thereby allowing ratification of a formal life extension for the engines fleetwide.

The drive to improve performance and reliability of the engine was made from as far back as 1985 when sufficient time remained to make modifications cost effective. Furthermore, the Tyne engine overhaul policy was changed in 1986 to introduce what was called the 'Hot End Overhaul' at alternate 5,000 hour intervals, with little or no other work on remaining parts of the engine, the intention being that the engine would effectively achieve 10,000 hours between full reconditions as a cost savings measure. However the results of the introduction of this policy were to :

- increase the number of pass off test bed rejections mainly due to LP compressor vibration,
- increase the number of rejections of in-service engines at low running hours due to cracked LP compressor vanes, vibration and bearing problems in the compressor section.

During this time the overhaul bases were also having problems in maintaining their normally high standard of quality. The net result was that in the years 1987 and 1988 the Premature Removal Rate increased (Figure 5).

MOU Gas Turbine Intervals Between Overhaul			
Engine Variant	RR Declared Overhaul Life	New Declared Overhaul Life	Remarks
Olympus	5000 hours or 10 year Calendar Life	Calendar Life 16 years	Subject to 2 yearly inspection after 10 years
		Frigates & Destroyers : 5500 hours	Subject to periodic inspection
		Carriers : 7000 hours	
Tyne	5000 hours	6500 hours	
Spey SM1A	3000 hours (12.75MW)	6000 hours	
Spey SM1C	9000 hours (12.75MW)	9000 hours	Lead engine currently at 2500 hours

Table 2 - MOU Gas Turbine Intervals Between Overhaul

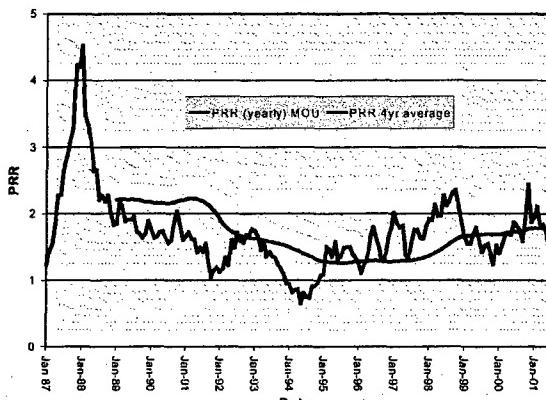


Figure 5 - Tyne Premature Removal Rate (PRR) since 1987.

The above situation was made somewhat worse by increased military tension in the Iraq-Iran war with the numbers of engines in ships with both navies reaching the maximum. Firstly, this had an increase in the number of Policy removals to the overhaul lines and secondly, this caused a demand for production engines that had hitherto been used in support of the pool of engines. This severely reduced the level of serviceable engines in the common pool.

Recovery actions commenced from late 1987 with a review of test bed rejections and overhaul procedures carried out with the full co-operation of the two engine overhaul bases at Rolls Royce and the Naval Aircraft Repair Organisation. This identified the main areas which needed attention in the cold end of the engine and resulted in an improved work package called 'Hot End Overhaul and Cold End Repair', which was subsequently re-termed the 'Mini-Overhaul' which has proven to be a successful policy.

Being a mature engine with a reducing fleet size and noting that changes can be expensive, the Tyne engine now uses a much stricter modification policy than preceding years. Modifications are now approved only if they relate to safety, obsolescence or operational reasons with the development of the engine constrained to improvements with an assured and short payback time.

Emphasis has been placed on the completion of the embodiment of existing modifications, particularly where these are known to improve reliability. The relaxation, where possible, of in-service acceptance limits has been adopted in preference to modification action and in this respect it was agreed to adopt a fairly conservative approach with the Design Authority. Recent years have showed a steady increase in engine life, pushed by increased confidence in improved in-service inspection techniques and pulled by the wish to reduce cost. The PRR during this period moved upwards as a consequence of the significant increase in planned life but in general reliability for the engine still improves.

In 1998, a total of 5 engines ran in excess of 6000 hours prior to removal (7246 hours being the highest) as did a further 9 engines in 1999 (7898 hours being the highest) increasing to 10 engines in 2000 (6587 hours being the highest). Compare these figures with 1987 where no engines achieved anything greater than 5500 hours operation.

#### The Olympus Life Extension Programme :

The above detail of the Tyne life extension programme is provided by way of example. In addition, a similar programme is in place

for the Olympus in MOU operation where they are used in naval Frigates as sprint engines and in aircraft carriers (CVS) as main propulsion prime movers. As such, the operational profiles and fueling considerations between the two roles differs significantly with the carriers undertaking as least six times the amount of usage (approximately 1800 hours per year per engine) as the rest of the DD/FF fleet (averaging 300 hours per year per engine). With all engines fundamentally 'interchangeable', it has been necessary to undertake a degree of tailoring of the overall Life Extension Programme for the Olympus.

The original IBO is 5000 hours but with such low usage for the majority of the fleet there is a Calendar Life condition attached which effectively means an engine must be returned for overhaul after 10 years, regardless of whether it has seen service or not.

Through a similar program to the Tyne in which a number of defined internal endoscope inspections are undertaken alongside condition assessments, the MOU have yet to remove an engine based on Calendar Life. Indeed, the lead engine in service is now approaching 17 years since installation and will be removed in 2002 to undertake a detailed assessment at overhaul in order to confirm acceptability of the current practice.

In addition, the other element of the programme is the drive to increase the IBO for engines installed in the carriers where, in terms of their higher running hours, the engines have proven themselves to be very reliable. Following a detailed life management plan, the programme currently allows CVS engines to operate up to 7000 hours prior to removal.

Compared with the Tyne engine, modification and maintenance efforts have been much lower with only two failure modes serious enough to justify modification action (discounting the improvements made to Combustion Cans which are covered later in the text) :

**HP Turbine blade failures :** During 1985, 9 premature removals were experienced due to HP Turbine blade failure all at varying hours run with the symptom of excessive vibration and resonant frequency excited by combustion defects. To reduce the vibration induced high cycle fatigue (HCF) a number of key measures were taken; a) improvements were made in the combustion area - a high number of combustion cans showed production deficiencies and a number of burners were partially blocked necessitating a burner calibration campaign, b) the vibrational sensitivity of the HP turbine blade was designed out by introducing an interlocked shroud and cast Inconel blade thereby helping to damp out the first flexible mode of vibration. Recent HPT failures on 3 engines are under investigation.

**Starter motor drive bracket failures :** There has been a lengthy history of low numbers of engine rejections caused by starter bracket cracking, rising to 11 such failures in 1988. During the period 1989 to 1992, for reasons unknown, the number of failures increased to 19. The main failure mechanism was identified as a high torque loading during the first phase of the start-up operation and a number of high stress areas in the starter motor bracket, therefore two modifications have been embodied in the fleet to overcome the problem : a) a 'soft start mechanism' allows a reduction in the initial torque by applying a much slower pressure rise during the first phase of the start and b) a more robust design of bracket is fitted. The

number of failures has reduced significantly, however, we are monitoring operation.

The effect of the improvements is clearly visible in the Premature Removal Rate (PRR) graph (Figure 6) where there is a marked increase in removal rate due to starter bracket failures and HP turbine blade cracking from 1990 to 1994. The effects of the burner campaign and 'soft start' modifications during the later years are also clear, however, a general decline in Olympus operation accompanied by a steady trickle of engine failures has lead to reduced reliability which is again being addressed. The PRR is currently low with a number of recent failures (other than HPT) being caused by incidents which are not engine related.

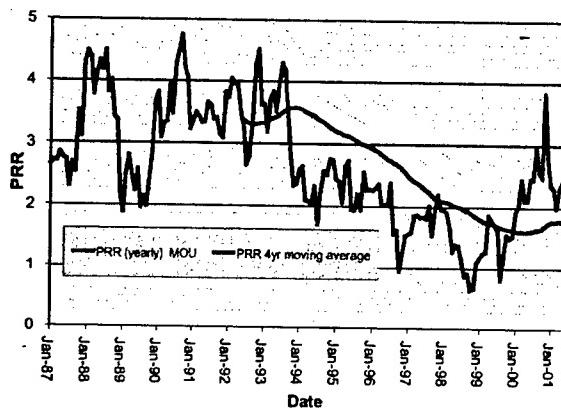


Figure 6 - Olympus Premature Removal Rate (PRR) since 1987.

#### **The Spey SM1A Life Extension Programme :**

The Design Authority has set planned lives for individual modules of the engine (MACU's) from the onset. From a user perspective with many years of experience, the MOU requires that the IBO's are extended (where service experience allows) in a similar manner to the programmes in place for the Olympus and Tyne. Being a modular engine, the low life MACU's are being targeted first; the objective for the Spey SM1A programme is to extend minimum MACU life in stages from the baseline of 3000 hours up to 6000 hours, 7500 hours and (longer term) to 9000 hours.

Again, Life Extension Programmes consist of a series of in-service inspections on a small number of engines at specified intervals. Opportunities are also taken to inspect engines returned for MACU repair if it is felt that there is some value to be gained towards the programme.

From the recent completion of life assessment rebuilds on three high life units (two at 5500 hours and one at 6500 hours of operation), it is clear that the first phase has been successful. Ratification of an increase in Turbine MACU life is expected shortly with an increase from 3000 to 6000 hours. Whilst a modification may be required, we shall be looking to go beyond this. Furthermore, other MACU's have already been extended to 7500 hours, the intention being that these MACU's will be subjected to abridged examination of the critical components identified from previous work conducted during life assessment activities. This self imposed, self regulated extension programme has meant an increasing degree of risk and engine management on MOU operators. Of note, is the protracted timescale for events with a general decline in annual operating hours. The current highest life SM1A in service is operating at 6182 hours. Even at

today's usage rate this will take nearly 4 years to reach 7500 hours subject to passing strict inspection routines and performance assessments. Spey SM1A Mean Time Between Removals is portrayed graphically in Figure 7.

In terms of savings, this is dependant on increasing discreet MACU lives which may well evolve into a 'mix and match' basis as engines are returned back to service from repair or overhaul. For example, the additional 3000 hours extension in planned life of an 04 Turbine MACU represents one less engine removal and replacement operation, one less MACU exchange and one less Turbine overhaul, a saving of approximately £ 450 K through life. Increasing this life further to 7500 hours in line with the programme for two other MACU's on the engine represents two less engine removals, three less MACU exchanges and three less MACU overhauls, a saving in the region of £ 650 K per engine through life.

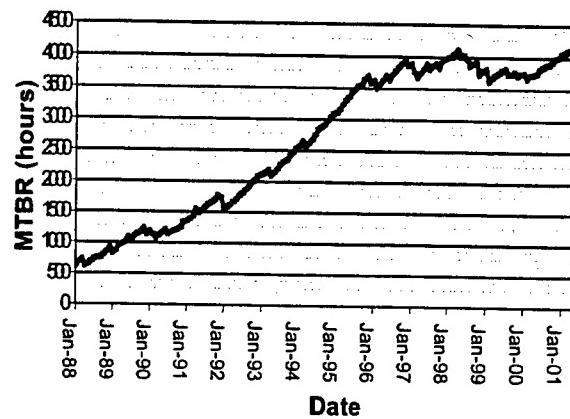


Figure 7 - Spey SM1A Mean Time Between Removals.

#### **Component Life Assessment and Extension Programmes :**

##### **Tyne Fuel Pump Life Extension Programme :**

Tyne Fuel Pumps are currently lifed by the OEM at 2500 hours of operation based on the reliability of the pump's Piston Spring. Whilst MOU partners have previously conducted spring changes in service to allow further life extension, this practice has recently ceased due to Health and Safety implications with the presence of asbestos parts until replacements are embodied across the fleet. The RN have traditionally followed this policy by replacing units on achieving life and on the basis that the Tyne fleet achieves approximately 77,000 hours average annual usage, this equates to a baseline arising of 31 units per annum. Following a review of the modes of failure, a decision was made by the RN to extend Tyne fuel pump life to 3500 hours, approximately 2 years engine usage. Prior to replacement with a springless design, similar Olympus sprung fuel pumps could remain in service for 8 years prior to removal so this track record has been exploited.

Fleet experience shows that the majority of Tyne Fuel pumps are now achieving beyond 2500 hours without degradation in engine performance, however a formal Life Extension Programme which tracks the characteristics and wear mechanisms of selected units passed the 3500 hour point has been set up with the Design Authority with OEM support and advice.

**Proposed savings :** Increasing Tyne fuel pump life from 2500 hours to 3500 hours reduces the number of repair arisings from 31 units to 22 units per year representing a direct repair cost saving of £ 305 K per year. Additional benefits also include the reduction in ship staff activity to remove items, less engine down time and a reduction in the number of spare assets required.

Subject to the outcome of the lifting investigation the plan is to drive fuel pump life further, initially to 4000 hours, thereby reducing the number of repair arisings to 19 units per year (attracting a repair cost saving of £ 406 K per annum) and then on to 4500 hours (with a reduction in repair arisings to 17 units per year with an associated saving of £ 474 K per year). With such a phased approach and the potential to life 'on-condition', the programme should mature within two to three years with many years remaining to run.

#### **'On Condition' Component Lifting Policies :**

At the request of the RN and in addition to discrete studies on all engines, a recent review of Spey accessory Critical Component Lives imposed during operation proved that sufficient running evidence was now available to explore a transition to 'on condition' maintenance policies for a large number of on engine components. The items selected for study were effectively minor components that ship staff have access to replace during the application of prescribed maintenance, whether on a cyclic or calendar basis. Such items include the Spey HP and LP Compressor Bleed Off Valves (HP and LP BOVs) and the Spey combustor Low Pressure Atomisers (LPA's). The principle applied was to review the reliability, probability and consequence of failure for the components selected and then, on the basis of successful operational experience, re-classify those items whose failure now presented a tolerable (or lower) hazard to ship staff or to the safe operation of the vessel. A number of real improvements have been made. In addition to the savings in part repair and overhaul, other benefits have included better component life management, reduced operator maintenance and a reduction in the CAL ('carried on board' allowance).

#### **Tyne Power Turbine Metastream Coupling Life Extension :**

The Tyne primary gearbox Metastream flexible coupling is currently lifted by Rolls Royce at 21,200 hours of operation (approximately 12 years service), however, a review undertaken recently suggests that the OEM has never applied a finite life to the coupling and that it should be possible to extend the imposed limitation by as much as 50 % or more.

With the exception of one particular RN ship, instances of Metastream coupling failure in service are rare with many units now approaching their current life of 21,200 hours.

Of the 22 issues since 1996, only 2 have been made to operational vessels. The remaining couplings have been used to support prescribed maintenance activities during ship refits, possibly unnecessarily, as replacement has routinely been included in the work package irrespective of remaining life on the unit, or if the balance of life is insufficient prior to the next Refit.

With this in mind, we are proposing that a life extension from 21,200 to 26,000 engine running hours is adopted for the Tyne power turbine Metastream coupling, subject to ship staff inspection every 1000 hours from the Current Planned Life. This is the first phase in a programme to validate an 'on condition' lifting policy,

reflecting a shift from prescribed calendar based exchange to Condition Based Maintenance. Current indications are that this will provide a saving of £ 75K per annum based on evidence from refit work package cost analysis.

#### **Olympus Air Starter Motor (ASM) Life Extension Programme :**

With an overhaul cost of £ 12.5 K per unit, a fleet arising of 22 units per year and a lengthy turn around time, Olympus air start motors are a high value annual investment in terms of R&O activity. There are, however, a number of critical issues which must be born in mind when forming a Life Extension Programme for this accessory as there are cyclic fatigue issues with their rotative components which must be considered.

The rotor disks are lifted by the OEM at 7,500 cycles, however, the current IBO for Olympus air start motors is defined by the Design Authority as 1,250 cycles, each cycle representing one operation. That said, a Special Reporting programme shows a high number of ASM's achieving in excess of 2,500 operations over a number of years. Analysis of the removal data, combined with a drive to reduce the burden of managing a lengthy and somewhat unrealistic overhaul programme, suggests that the majority of Olympus air start motors achieve their full overhaul life before removal and can therefore be formally life extended past their current IBO.

Through a managed programme the aim will be to extend the overhaul life initially to a revised life of 2,500 operations and, following successful overhaul assessments and in increments of 750 operations to the rotor disc life of 7,500 operations.

Doubling the current IBO to 2,500 operations represents an R&O saving of £ 135 K per year. Based on rotor disc life, this saving rises to £ 225 K per year.

#### **Combustion Can Life Extension Programmes :**

**Olympus :** Introduction of improved standard OLG301 combustionware has lead to an increase in life from 2000 to 4000 hours of operation. Through further in-service running and inspections, the life of the non igniter combustors has been increased to an 'on condition' basis with further potential to achieve 8000 hours of operation, thereby halving the arisings and associated expenditure on overhaul.

Proposed savings; at a current rate of arisings of 36 combustors per year and an associated overhaul cost of £ 2.7 K per combustor, this represents a direct annual cost saving of £ 49 K per year not including the projected maintenance and engine availability benefits.

**Tyne :** In a 'cruise' role, Tyne engines accumulate by far the largest proportion of annual usage, sometimes remaining online for periods of 24 hours or more during any one period of operation. The demands on the engine and its ancillaries in terms of reliability and availability are therefore very real, with a mission profile closely approaching that of a commercial ferry during operation.

The combustionware aspects of the engine have proved to be generally acceptable and through discrete inspection programmes lives have gradually increased to the current position where, following a review of service experience at the

request of the RN, Rolls Royce have recently re-classified Tyne combustion chambers to an 'on condition' lifing policy.

Current inspection requirements alternate the use of ship staff and in-service support desk officers at periods of 2000, 4000, 5000, 6000 and 6500 hours but, in comparison to the service offered by the support desk, it could be debated that ship staff inspections rarely unearth defects as the level of expertise is low and there are limitations to on-board inspection equipment. We are proposing that ship staff inspections are discontinued in favour of a 'mid life' inspection by support desk staff at 4000 hours followed by further inspections at an inspection frequency set by the officer based on the results of the inspection through to 6500 hours of operation.

A review of results will be undertaken prior to relaxing all current programmed inspections up to full combustor life of 6500 hours. Clearly, this programme does not fully support the Rolls Royce recommendations but shows the benefits of user experience and enables other possible factors which may also have a significant impact on combustor life to be considered, such as burner degradation and engine optimisation procedures.

Further, the majority of burner changes are still conducted as a direct result of programmed inspection requirements. Reducing the number of inspections has financial advantages in terms of reducing burner overhaul arisings. Based on the proposed revision to inspection frequency, Tyne burner overhaul costs could be reduced by as much as £ 50 K per year from implementation of the programme.

**Spey :** Spey gas turbines introduced into RN service in 1986 were originally fitted with 'VZ' combustion cans which tended to form brittle flakes of carbon on the Reflex Airspray Burner (RAB). Fleet experience up to 1991 showed that carbon shedding could lead to damage occurring on the leading edges of the HP turbine blades and Nozzle Guide Vanes so the Improved Reflex Airspray Burner (IRAB) was introduced to eliminate the problems of erosion on hot end components. Set against a can life of 3000 hours, experience has, until now, been disappointing with the 'boost' profile of the engine placing a significant demand on combustionware. Early IRAB are prone to cracking accompanied by material loss, holing and 'green rot' (fluxing sulphidation). The life of this standard of can is currently about 2200 hours depending on where fuel has been embarked and significantly, the level of sulphur.

Of note is the fact that the Japanese Navy operate Olympus, Tyne and Spey on low sulphur fuel (typically 0.05 to 0.15 % Sulphur). Their running hour experience is extremely high and they have, reportedly, no associated problems as a result, typically achieving combustion can lives in excess of 4500 hours.

The current in-service IRAB design, SPG 711, introduced by modification campaign in 1996, is presently the preferred standard with in-service lives now just past 3000 hours. It is clear that increased combustion temperatures have a debilitating effect on can life so every effort has been made to reduce skin temperatures by using an additional row of angled effusion holes in the vicinity

of the 'Y' ring. Other enhancements include full coverage bond and thermal barrier coatings (TBC), a single piece pressed flare combustor head instead of the welded two piece design and Nimonic 86 transply in the RAB end cap which increases flow of cooling air to the cold face of the RAB. Improvements have lead to real reductions in the levels of carbon and smoke, particularly at part load. IRAB have also all but eliminated 'hot end' erosion and holing so profound with earlier 'VZ' combustors.

It is now feasible to run past 3000 hours with SPG 711. There are significant savings to be made in this area, a recent study showing that over £ 1.5 M can be saved in repair costs over the remaining life of the RN Frigates through combustor life extension and through re-use of combustor discharge nozzles.

#### Operation and maintenance :

##### **Maintenance methodology :**

Considerable differences in operation and maintenance exists between a naval gas turbine and its aero counterpart. Personnel involved with aircraft are trained to work in a strictly regulated manner, however, the naval environment requires a more pragmatic approach but there are limitations in that ships staff do not gain sufficient experience to become specialists while on board. A number of mechanisms are in place to overcome these restrictions :

- Experienced engine specialist teams have been formed - the RN unit is currently based at MPS214 in Bath to assist ships on demand. Corporate knowledge is maintained through a mix of civilians and uniformed personnel.
- 'Upkeep by Exchange' (UxE) is the base philosophy for repair of the gas turbine onboard ship, thereby reducing the amount of specialist fault finding required and hence the skill requirement.
- Defect communication between ships and the specialist teams is maintained using the latest techniques including image transmission equipment ('Photo Phone'), which recently acquired a stereo tip measuring head to detect the size of cracks and depths of pitting visible through the endoscope eye piece.
- Onboard repair techniques have been developed and retained by the waterfront repair and specialist technical groups.
- Specialist dockyard teams have been created to carry out engine replacements.

##### **Tyne Power Reduction :**

In an early attempt to discover why large differences existed between RN and RNLN Tyne Demonstrated Mean Achieved Life (DMAL – Figure 8), the records of engines at overhaul bases were interrogated in the late 1980's to establish whether any trends were evident.

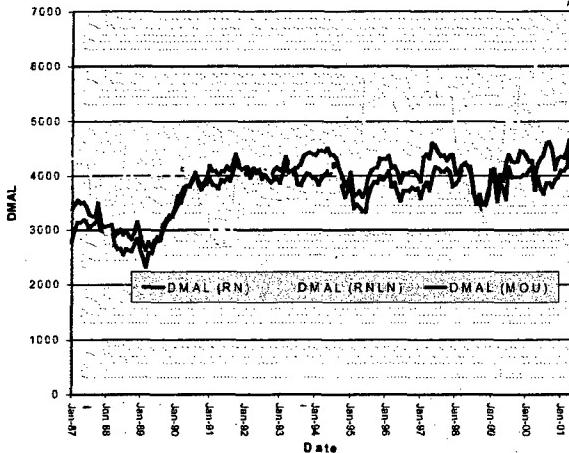


Figure 8 - Tyne Demonstrated Mean Achieved Life (DMAL).

Two families of engine were established through evidence of the condition of hot end components; scrap levels were high overall, but the components from the RN engines were significantly worse. The combustionware, NGV's and rotor blades on all engines showed signs of high or excessive temperature operation. A study of operational usage indicated the RN spent a slightly higher proportion of its time at higher power levels although at the time this was thought not to be significant. The RN/LN undertook a trial of two Tyne engines at 90 % power to establish the effects of lower running temperatures and the impact on operational capability. One of the engines became available at overhaul and was found to be in excellent condition. Furthermore, the RN/LN identified that most of their operational requirements could be met using the 90 % power level despite the figures that had been drawn up in the original Staff Requirement. In the middle of 1989 both Navies adopted the practice of operating their Tyne engines at the reduced power level of 90 % (Figure 9).

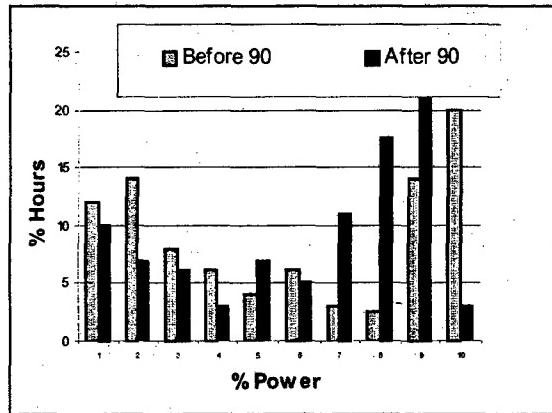


Figure 9 - Tyne engine powerbands showing 90 % rescheduling.

#### Tyne Engine Optimisation Procedure :

Today's DMAL for RN Tyne engines typically averages 4000 hours but this is 20 % lower than the figure for the RN/LN at an average of 5000 hours achieved.

Clearly, analysis has been ongoing to fully understand the reasons surrounding the difference including investigations into bearing failures and oil hygiene standards, however, these have all proved somewhat inconclusive. A separate study by the RN, with much

liaison and assistance from the RN/LN, recently compared engine operation, operator training and setting to work aspects with surprising results.

Observations concluded that somewhat unknowingly, the operating procedures in place routinely allowed the RN to over power its engines. This was evident through;

- the use of the LP RPM method of engine optimisation in an attempt to maintain original 'pass-off' compressor speeds without taking into account that higher lives can significantly degrade cycle efficiency leading to over fueling of engines and increased thermal degradation of hot end components,
- an inability (or misinterpretation) in applying the 90 % fuel flow limitation in service as discussed in previous text.

With the recent fitment of more accurate fuel flow meters in RN service (now within the  $\pm 1.2\%$  accuracy demanded by the Design Authority), a recommendation is currently being drafted for the Command to adopt the fuel flow method of optimisation across the MoU fleet, to prevent 'over optimisation' of engines.

By increasing RN Tyne DMAL from 4000 to 5000 hours in line with the RN/LN figure, the potential cost savings to the MoU are represented in the reduction of premature engine removals by as much as 2.7 engines per year, equivalent to a support cost of £ 900 K. If the proposed DMAL target is achieved then the reduction in fired hour cost could be as much as 14 %.

Similarly, by striving to increase both RN and RN/LN DMAL from 5000 hours to 6000 hours, a further predicted saving approaching £ 1.0 M per year could be made, potentially reducing hourly running costs by as much as 20 % from today's figures (Figure 10).

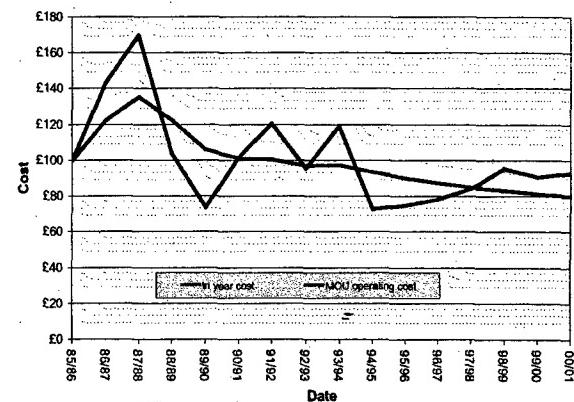


Figure 10 - Tyne hourly operating cost.

#### Improvements to Spey HP Bleed Valves (HP BOVs) :

Unlike their aero cousins, failure of the HP BOV (and associated Shutdown Control Valve) is a predominant early feature of unreliability for the SM1A and SM1C where the valves were found to be intolerant to fluid carry over into the air bleed system from compressor washing. Problems were experienced with gumming of the carbon seals accompanied by pitting corrosion of sliding surfaces.

In the short term, interim procedures for in-service valve reclamation were introduced followed by a requirement to prove operation of each unit after shut down for long periods. This, however, was somewhat tedious and presented operational difficulties. In addition, and to overcome the burden of additional maintenance, a long term solution was identified :

- A valve improvement campaign has begun. This entails chrome plating internal sliding surfaces accompanied by a new chemically nitrided centre bush which resists the galvanic couple when used with other materials in the valve. Two valves are in service on RNLM SM1A ships with very satisfactory performance so far.
- The timing point for injection of washing and inhibiting fluids has been re-scheduled to occur 15 seconds after starter cut off. This has had the effect of dropping spool speeds sufficiently enough to allow compressor cleaning but more significantly, in terms of BOV operation, has prevented wash fluid escaping up into the bleed ducting.
- A 'back to back' engine trial is underway to evaluate whether there is actually a need to undertake compressor cleaning (see text below).

#### **RN trial aimed at deletion of compressor washing and inhibiting :**

Original Spey washing and inhibiting routines traditionally carried out to restore engine performance and prevent corrosion were originally derived from the aero Spey which used untreated steel components in the compressor although the marine Spey uses high grade titanium and sacrificial coatings. As such it could be argued that the marine engine is not as susceptible to corrosion.

A ship trial which began in 1999 and is almost complete, is being run to monitor and assess the effect on performance when compressor cleaning and inhibiting are discontinued. This has required a 'back to back' approach with one engine acting as a baseline receiving water washing and inhibiting routines in the normal manner and the other engine receiving no activity at all.

There are many anticipated benefits available through deletion of washing and inhibiting :

- in terms of operability: reduced maintenance penalty and greater engine availability through less disruption to the ships propulsion configuration,
- in terms of performance: increased reliability of LP and HP BOVs, better anti fouling resistance of compressor blades (less gumming), increased starter motor lives through reduced operations and a reduced risk of downstream effects,
- in terms of health and safety: less operational and maintenance risk to ship staff through a reduction in HAZMAT fluids and the disposal of such fluids,
- in terms of materials and stores: a reduction in compressor cleaning fluid purchases and onboard stores and a reduced demand for compressed air required for engine washing and drying out operations.

Results to date indicate that with the unwashed engines in both trial ships engine health and performance has not suffered any discernable amount that could give rise to problems with a lack of power, high temperature operation or early governor interaction. Furthermore, salt fouling of compressors has been tolerable which brings the frequency of water washing into question. It is

suspected that the oily film which has been identified on LP compressor blades is as a result of exhaust gasses from the diesels or the gas turbines themselves being drawn into the engine air intake. It is unlikely that airborne pollution is to blame especially in the marine environment.

Without wishing to pre-empt the final study report, and despite some initial scepticism, it is clear that there is little benefit to be gained by water washing and inhibiting engines in a marine environment. Furthermore, indications are that as a minimum a significant reduction in the frequency of washing will be possible, perhaps even culminating with a 'once per year' routine rather than the current 48 hour operation on the Spey. In conducting a routine at such a reduced frequency, there is also a need to address the quality and effectiveness of the actual procedure and chemicals used if a much increased periodicity between washes is recommended.

No attempt has been made to quantify the extent of the benefits which can be made, sufficient to say that it is understood there are a number of very interested parties in the results, a presentation of which is planned for ASME 2002. However, prior to this time, discussions to adopt a similar practice for Olympus and Tyne operation are already underway.

#### **Periods of engine inactivity :**

Ships are often inactive for prolonged periods because of leave or maintenance periods. As the engines are not used during these periods, fuel system components become sticky, oil coolers degrade and oil wetted internal surfaces and bearings are prone to corrosion due to humidity and drain down. The last point in particular has lead to an increased incidence of bearing rejections at overhaul due to surface corrosion. Measures in place to address these issues include :

- Introduction of OX22 lub oil: lubricating oil has been replaced by a specially developed synthetic marine gas turbine oil (OX22) that includes a better anti-corrosion additive package to reduce internal corrosion and attracts reduced cost,
- On-engine fuel systems: engine fuel systems are kept primed and closed during major maintenance activities and then 'exercised' before engine run up,
- Dehumidification: conservation measures are in place to protect engine gas paths against corrosion during maintenance periods,
- Introduction of Titanium SW/LO Coolers: A study in 1999 revealed that 21 Spey and Tyne engines (mainly in RN service) had been removed due to bearing failure which could be attributed to seawater lub oil cooler (SW/LO) tube perforation. Despite specialist assistance, however, the reason for failure had gone largely unresolved until the RN conducted a study of the sources of contamination at the time of failure and combined this with the dates of any maintenance conducted and with work that was underway with fuel tank corrosion. Tube failures were found to have been caused through the presence of 'Sulphate Reducing Bacteria' which attacked the oxide film on the inside of the tubes leading to Microbial Induced Corrosion. The phenomenon was most evident in estuarial waters when coolers had been shut down for maintenance. In these conditions the microbes thrive on the sulphate rich water in low levels of oxygen. From this discovery, the WSA embarked on a programme to replace existing

Copper Nickel cooler tubestacks with items manufactured from Titanium. This activity was combined with increased ships husbandry to drain cooler bodies if periods of inactivity were going to be longer than two weeks. Replacement by a titanium tubestack will ensure 100 % integrity under all operating and dormant conditions. Inspections to date indicate the tubestacks in service are in an excellent condition with no indications of any electrochemical or galvanic action. Furthermore, there have been no new failures in service.

As previous failures were unwittingly taken as 'the norm' over the fifteen year reign of bearing problems, implementing a strategy to resolve the cooler problem directly reduces the premature removal rate whilst providing a significant financial return of at least £ 0.5 M per year in reduced R&O activity.

#### **Steel exhaust gaskets as a replacement for fibre items :**

Asbestos free gaskets were introduced into the Tyne and Olympus inventory in 1994 to eliminate asbestos from main propulsion uptake systems. Whilst these meet Health & Safety legislation, they were proving unreliable averaging 25 RN Tyne and 30 RN Olympus gasket failures per year. As a replacement for asbestos, in 1991 the RNLM introduced a re-usable stainless steel gasket using Silksot high temperature sealant. This was subsequently introduced as a standard fit across the RNLM fleet in Tyne, Olympus and Spey uptake systems proving to be both reliable and cost effective. A similar programme is now underway to embody this modification on all other MOU gas turbine vessels. A phased implementation is envisaged during Upkeep Periods or lightly loaded Maintenance Periods, however, there will be an offset in potential savings against procurement and installation costs and replacement of previously good gaskets.

For Olympus and Tyne, the steel gaskets are low cost items at around £300 each, however, by preventing failures from occurring with fibre gaskets, the steel replacements being a 'one-time' investment represent a typical saving of approximately £ 340 K per year with a consequential increase in engine availability to the command.

#### **Leaving engines installed during major maintenance periods :**

In terms of engines removed during maintenance, 'Policy' removals concern the removal of serviceable engines when, for example, a ship enters a Refit Period or there are insufficient hours to undertake the next deployment. In terms of Tyne operation prior to 1989 a large number of these engines would go to the overhaul base for overhaul (sometimes both engines from the same ship if running hours were equal). Between them, the Navies agreed that engine hours needed to be managed such that there was a difference in running hours between the two propeller shafts, basically designating a preferred engine with the objective of ensuring that when a ship entered a period of maintenance requiring both engines to be removed, one engine should have useful life remaining thereby allowing it to remain in-situ, rather than both having insufficient life for deployment.

The minimum engine hours allocated for all regular deployments were also reviewed. A study of the historical records revealed that a strong case could be made for reducing the number of engine hours required for deployment providing that one engine met minimum criteria in terms of remaining hours. These two actions reduced policy removals by as much as 5 Tyne engines per year. Similar policies to leave engines in-situ during maintenance have also been accepted for Olympus and Spey unless specific issues with the hot

end mean the engines must be removed for inspection, repair or overhaul. With an average of 10 policy removals per year between ship classes, this initiative delivers a saving of approximately £ 200 K per year.

#### **Photo-Phone inspection diagnostics :**

Recent technological advances in digital processing and the ongoing development of e-mail now allows the RN support desk and other MOU operators the capability of offering a sophisticated imaging and analysis service when conducting planned life engine inspections or during fault finding procedures. Accompanying this initiative has been the fleet wide introduction (to gas turbine powered ships) of the 'Photo-Phone' system which allows ships on deployment an opportunity to communicate endoscope inspection images and written text by modem in real time to a fixed land line for analysis and / or in seeking advice by specialist or Design Authority staff.

This allows a very high degree of flexibility in terms of resource allocation whilst reducing response times thereby allowing better programme management and improved decision making.

Hardware is fully supported by Olympus Industrial and ImageBase Technology Ltd., both of which strive to retain close links with the RN support staff in order to incorporate any new technology as and when it becomes available into the suite of inspection equipment held by the desk officers. Recent advances include the provision of endoscope probe tips incorporating a stereo measurement facility allowing increased accuracy in classification and size of defects. Typical examples where this has been an advantage have been during the measurement of crack lengths in Spey transply combustion cans and during the classification of Tyne HP nozzle guide vane (NGV) leading edge perforations. The equipment also provides a reliable source of high quality data in which to base engine Life Assessment and Life Extension recommendations.

#### **Reliability Centered Maintenance (RCM) :**

As a Condition Based Maintenance tool, RCM is not new. However, it has only recently been introduced on the Spey engine in operation with the RN Type 23 Frigate as an alternative to the previously prescribed Planned Maintenance Programme. Whilst the level of maintenance required has been reduced, the emphasis is now on better placement of the maintenance resource with much more consideration for undertaking maintenance when performance deteriorates rather than on an autocratic basis. Following a Failure Modes, Effects and Criticality (FMECA) review and with the full support of the Design Authority, the first ship is due to receive the revised maintenance methodology in trial format later this year with full platform RCM roll-out occurring in early 2002. It is somewhat early to draw conclusions as to its effectiveness, however, RCM has been successfully adopted in the RN Hunt Class Mine Counter Measure Vessels.

#### **Component rejection criteria and acceptance limits:**

##### **Interpretation of limits :**

Late in 1989 and in the early part of 1990 a sudden occurrence of Tyne rejections due to internal failures of an external

gearbox was noted, some of these occurring at relatively low running hours. As engine removals were assessed, it soon became clear that one of the two overhaul bases was responsible (at the time) and following investigation was found to be misinterpreting the requirements of the overhaul specification. With the problem now corrected, the premature overhaul of Tyne gearboxes, and hence support costs, reduced significantly. This is an early example of the need to carefully monitor the acceptability and effectiveness of in service acceptance criteria.

#### **Relaxation of component rejection criteria :**

Clearly, there are gains to be made through relaxing rejection limits. For this reason collaborative programmes have been established with the Design Authority to extend the in-service rejection criteria of a number of components where feasible. Real successes have been achieved in the areas of combustion can limitations, NGV erosion / cracking limits and defects associated with turbine blades. However, human nature being what it is, overarching the criteria is the need for clear and responsible guidance in correctly interpreting any limitations imposed.

#### **Technology de-risking for new ship projects :**

##### **WR21 Neptune high velocity intake filter project :**

In order to safeguard marine gas turbines principally from foreign object damage (FOD) and salt ingestion there is a high degree of importance placed on the intake system, a principal element within which is the intake filtration equipment.

Since the introduction of marine gas turbines the RN have witnessed and participated in the development of intake filtration systems from knitmesh filters to highly efficient 3 stage separators (spray eliminators). Conventional layouts have provided many years of successful operation, however, not only do the systems themselves require a large amount of space (which is already at a premium), but they also introduce areas of weakness into the ship's structure resulting in a number of cracking problems currently evident on several classes of ship.

A design and development study is currently underway between the RN and Altair Filters Ltd., one of the principle MOU intake filter manufacturers. The project has been established to look into the possibility of moving away from conventional separators to the use of new generation high velocity spray eliminators with a view to both commercial use and, at this time, confirming the suitability of the equipment for the intakes of the WR21 Intercooled Recuperated gas turbine chosen for the new RN Type 45 Frigate, the challenge being to build a compact, faster spray eliminator using a much smaller plenum chamber. This, however, necessitates an increase in the velocity of the air to be processed, the problem being to ensure there is no relaxation in the efficiency of the salt particulate and water separation. Advantages being explored include reduced procurement costs, reduced maintenance costs and reduced radar cross section.

With a clear aim of de-risking the technology and using the data to calculate intake sizes prior to incorporation into the Type 45, the design route chosen uses a hardware demonstration and evaluation phase (Figure 11) followed by back to back testing of a 'Neptune' system with a conventional unit onboard an RN Type 22 Frigate (Figure 12).



Figure 11 - Neptune high velocity filter during development testing.



Figure 12 - Neptune high velocity filter trial - HMS Coventry (Neptune filter left, conventional spray eliminator right).

HMS Coventry was chosen because the ship operates with rear facing intakes that are not sheltered thereby providing a harsher filtration environment than on many other vessels and also because there was a convenient fitting opportunity in the ships programme followed by operation in UK waters before going further afield.

At the time of writing, initial results indicate that the trial, which is due to end in November) is progressing well, with the Neptune unit performing as good as, if not better than, the conventional system. It is the intention that a further insight into the results and conclusions of the trial will be presented at the next ASME Conference in Amsterdam 2002.

#### **Improvements in in-service support administration :**

##### **Formation of Integrated Project Teams (IPT's) :**

In recent years, improvements in customer supplier relationships have been made through the collocation of all the RN's marine propulsion support staff. Driving this challenge has been the formation of multi disciplinary groups which has lead, over the last two years, to a move in the Defence Logistics Organisation to the creation of IPT's. This has brought many benefits in the way we conduct business; in reducing operating costs, in achievement of key performance indicators and, ultimately, maintaining vessels at sea with zero defects. The main overarching improvement within the group has been in terms of communication and the increased teamwork of staff to achieve business goals. Furthermore, IPT formation has increased both internal and external customer liaison and

decision taking, even if this is achieved during a simple fleet enquiry such as in the team's ability to question a stores demand.

#### **Revised methods of support :**

The RN is exploring, wherever practical, the possibility of revised methods of Through Life Support. Where it represents value for money and makes operational sense, the transfer of responsibility for risk and support to contractors is being evaluated accompanied by incentivisation and gainshare techniques. As well as an inherent need for the contractor to provide a positive track record if they are to be considered in such an approach, there will always be a need to retain intelligent customer status, a characteristic which is extremely difficult to nurture and develop but all too easy to lose if due consideration is not given to all of the issues highlighted during the decision making process in any move to Contractor Logistic Support (CLS).

#### **Management of operational data and performance trend monitoring :**

During operation of marine gas turbines a generic approach towards maintenance has been established. To benefit from the accumulating knowledge, extensive data bases maintained by support officers collate information gathered during engine operation as well as accumulated during repair and overhaul activities. The information is processed and displayed in graphical form thereby enabling effective trend monitoring and allowing changes in procedures and equipment modifications to be evaluated in terms of reliability. Graphs used in this paper are based on the Premature Removal Rate (PRR) and Mean Time Between Removals (MTBR), trending techniques maintained for all engines.

#### **Compliance with Environmental Legislation :**

Current topics being addressed include :

- **Replacement of parts containing Asbestos:** Modifications to introduce alternatives to parts that contain Asbestos have been generated on all three engine variants and a replacement programme is currently underway for carried onboard spares and those required during repair and overhaul.
- **Replacement of Halon fire fighting gas:** As a potentially ozone depleting fire fighting gas, a Statement of Requirements for a replacement fire fighting medium has been generated and dialogue is in place with contractors to identify and develop suitable alternatives to the halon based systems in MOU operation. With the potential for increased risk of thermal shock from a water mist based system and the increased storage volumes and pressures of a CO<sub>2</sub> solution, the use of novel techniques such as pyrotechnically generated aerosols and inert gas generators are also being considered both for retrofit into MOU ships and for adoption in the RN Type 45 Destroyer.
- **Replacement of parts containing Cadmium :** Following the format for Asbestos replacement, modifications to introduce alternative parts to those that contain Cadmium are also being generated on all three engine variants and will be followed by a phased programme of replacement

#### **Managing obsolescence :**

Various strategies are being used to address obsolescence issues as and when they arise either ;

- through the purchase of 'one-off life time buys',
- by cannibalising assets that are considered surplus,
- by development of unique alternatives with manufacturers.

Rolls Royce support in providing Design Authority guidance is preferred, however, in terms of customer support and experience, there is a move to the formation of direct partnership arrangements with original manufacturers. Components currently being addressed include the future support arrangements for turbine entry temperature amplifiers, igniters, vibration transducers and the Spey Analogue Fuel System Controller (FSC). It is worthy of note that Rolls Royce have approached the FSC issue by developing their own SMIC Digital Engine Control Unit (DECU) in collaboration with CAE Ltd. of Montreal, Canada. This design is being installed in the new RNLM LCF Frigate for which RN training facility assets were employed during DECU testing. Despite the improved availability aspects that a DECU allows in terms of a replacement for the analogue system in MOU service, it is, without doubt, a high value investment which in the current climate cannot be justified as cost effective.

#### **The Future :**

In terms of reducing Through Life Costs for aging prime movers, we see the way ahead as being one of continued vigilance and assessment of in service experience, searching out the drivers that decrease safety and increase operating costs and applying a no nonsense approach to achieve cost effective solutions.

In brief the following is our continuing approach :

- regard the Planned Life of an engine as being a target which may be exceeded in a controlled manner. Areas of risk will be further investigated and cost effective solutions found to allow increased running hours and lower removal rates to be achieved. The life of critical components will be respected,
- continue to develop, on a priority basis, improved in-service acceptance limits allowing extended running whilst managing risk,
- change, whether in configuration, maintenance or policy, nearly always involves expense, budgets have become tighter and therefore 'Financial Appraisals' have become a necessary discipline. The solutions adopted will have to pass the "How much ... ?" question, and if the answer is not "... a saving", then a very good technical case will be required,
- the maintenance policy for engines in service will continue to be 'Upkeep by Exchange' (UxE), rather than repair in-situ. This policy has advantages for the smaller navies of the MOU,

- the continued support of the engines in later years when numbers become fewer, will need to be carefully managed with the method of disposal of the ships clearly defined and respected. If ships are sold complete with gas turbines and a spares package, a balance between the requirements of the MOU partners and their customer's interests will have to be made. Should the ships be scrapped then the support position will be somewhat simpler but will be lead by operational requirements and ever present financial considerations,
- the future years will be approached with some confidence in that we can maintain existing performance and, preferably, improve on it in most areas.

In conclusion, the DLO has a testing strategic goal which aims to improve the overall cost effectiveness of support. We have recognised that there will still need to be a managed risk programme and that we will still need to produce solutions to 'in-service hurts' that are both cost effective and technically acceptable.

Most of the advantages predicted for a continuing gas turbine operation policy are being realised in practice, indeed, some of the anticipated disadvantages have not been as serious as expected. Warship availability has improved; it is proving possible to increase the intervals between overhaul to double those originally prescribed with significant benefits to the defence budgets; and marine engineering complements have reduced significantly, yielding further benefits in operating costs.

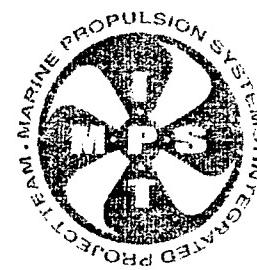
Finally; any views expressed are those of the author and do not necessarily represent those of the Department / Agency.

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#### Paper 4: Discussion

##### Question from D Shepherd – QinetiQ, UK

Are the planned lives of your naval gas turbines the same as the component lives?

##### Presenter's Reply

No, the planned lives represent the Interval Between Overhaul (IBO). Critical component lives are the lives of those components within the engine that, if failures were to occur, represent a hazard to operator or engine safety. These lives are usually much greater than the IBO. An example of life extension of the IBO for the Spey SM1A turbine is that life between overhauls, the planned life, has been extended from 3000 to 6000 hours, however, we still respect the critical component lives. We are currently in the process of validating exchange rates and operating profiles to support us in assessing whether we are actually able to progress further IBO extensions or, indeed, whether we have got the original assumptions wildly wrong, either to our advantage or disadvantage.